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Safety

NUCLEAR SAFETY REVIEW AND LAUNCH APPROVAL FOR SPACE OR MISSILE USE OF RADIOACTIVE MATERIAL AND NUCLEAR SYSTEMS

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This Air Force Manual (AFMAN) implements Presidential Directive/National Security Council Memorandum 25 (PD/NSC-25), Scientific or Technological Experiments with Possible Large-Scale Adverse Environmental Effects and Launch of Nuclear Systems into Space, dated 14 December 1977 (as modified 8 May 1996), DoDD 3200.11, Major Range and Test Facility Base, Department of Defense Instruction (DoDI) 3100.12, Space Support, Air Force Policy Directive (AFPD) 91-1, Nuclear Weapons and Systems Surety, and establishes the nuclear safety review and launch approval procedures for radioactive materials intended for space or missiles use. This AFMAN is consistent with the policy established in Department of Defense Directive (DoDD) 3100.10, Space Policy, and applies the guidance and procedures found in Air Force Instruction (AFI) 48-148, Ionizing Radiation Protection, and AFMAN 40-201, Radioactive Materials (RAM) Management. This manual applies to all Regular Air Force, Air Force Reserve, Air National Guard, Department of the Air Force civilian personnel, and contractors, if included in the applicable contract units that design, develop, modify, evaluate, test, and/or operate existing and future Air Force (AF) space systems (operational, test, and experimental), AF space support systems, and to organizations who use or operate AF launch facilities or ranges. The authorities to waive wing/unit level requirements in this publication are identified with a Tier ("T-0, T-1, T-2, T-3") number following the compliance statement. See AFI 33-360, Publications and Forms Management, for a description of the authorities associated with the Tier numbers. Submit requests for waivers through the chain of command to the appropriate Tier waiver approval authority, or alternately, to the requestors commander for non-tiered compliance items. Ensure all records created as a result of processes prescribed in this publication are maintained in accordance with

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SUMMARY OF CHANGES

This document has been substantially revised and must be completely reviewed. Major changes include the addition of a launch risk constraint criteria for the Space Wing Commander, the addition of requirements for missions involving reactors or fission devices, the deletion of an "A1" threshold for a Safety Analysis Summary (SAS) report, and an update of the requirements for the range users to provide technical support to Headquarters Air Force Safety Center Space Safety Division (HQ AFSEC/SES) and Space Wing Safety office.

Chapter 1

OVERVIEW

1.1. Defining Scope and Requirements. This manual defines the nuclear safety review and launch approval process for using radioactive materials aboard a space or missile system.

1.2. Nuclear safety review and launch approval procedures apply to:

1.2.1. Agencies that use any radioactive materials aboard a space or missile system (atmospheric, ballistic, orbital, or earth escape), including radioactive materials that the United States (US) Nuclear Regulatory Commission (NRC), Agreement States, or other Military Services exempt from licensing.

1.2.2. Any materials held under Section 91a and 91b of the *Atomic Energy Act of 1954*, Title 42 United States Code Section 2121 (a) and (b).

1.2.3. Air Force agencies that develop, test, or have operational responsibility for radioactive materials in space.

1.2.4. Other agencies or organizations that plan to use an Air Force facility, range, or other physical asset to launch radioactive materials and have not completed a range-approved or equivalent government agency safety review and launch approval process.

Chapter 2

ROLES AND RESPONSIBILITIES

2.1. Air Force Chief of Safety (AF/SE): may approve waivers requested by major command (MAJCOM) chiefs of safety to this manual. For special access programs, the Air Force Vice Chief of Staff or higher-level authority must grant waivers to this manual in writing.

2.2. Headquarters Air Force Safety Center will:

2.2.1. Perform Nuclear Safety Evaluation and Review.

2.2.1.1. Evaluate safety analysis reports, including Safety Analysis Summaries (SAS) and Safety Analysis Reports (SAR).

2.2.1.2. Provide the Department of Defense (DoD) coordinator for the Interagency Nuclear Safety Review Panel (INSRP).

2.2.1.3. Provide a quarterly forecast to the Assistant Secretary of Defense, Nuclear, Chemical & Biological (ASD (NCB)) of projected Air Force space or missile launches of space reactor systems (i.e. fission devices) or payloads using radioactive quantities greater than 0.1 % of the A2 values listed in the International Atomic Energy Agency's (IAEA) *Regulations for the Safe Transport of Radioactive Material*, SSR-6, Section IV, Table 2 as directed in Presidential Directive/ National Security Council 25 (PD/NSC-25).

2.2.1.3.1. A1 and A2 refer to the basic radionuclide values of radioactive material as established by the IAEA to determine activity limits and packaging requirements for the safe transport of specific nuclear isotopes (*IAEA Regulations for the Safe Transport of Radioactive Material*, SSR-6, Section IV "Activity Limits and Classifications", Table 2 "Basic Radionuclide Values", p. 25; 2018). The A2 values are used by PD/NSC–25 as the bases to set a threshold for INSRP empanelment and quarterly reports. This manual uses the A2 values to set a threshold for SAS reports, as shown in **Table 2.1**. This manual does not use the A1 value.

2.2.1.4. Ensure technical subpanels and/or working groups for INSRP launch abort and space nuclear systems have required resources.

2.2.1.5. Provide technical assistance to organizations developing systems that incorporate significant amounts of radioactive material.

2.2.2. Participate in the INSRP per PD/NSC-25. When a mission's radioactive materials are greater than 1000 times the A2 value listed in Section IV, Table 2 of the IAEA SSR-6, an INSRP is required, as established in PD/NSC-25.

Table 2.1. Threshold Requirements.

Threshold	Requirements
≥ 0.1% of A2 or a reactor	Quarterly Forecast Report, per PD/NSC-25
≥ A2 or a reactor	SAS Report & ASD (NCB) Approval
≥ A2 × 1000 or a reactor	INSRP Empanelment, per PD/NSC-25

2.3. MAJCOMs will:

2.3.1. Perform Annual Range Nuclear Safety Inspections. These inspections must evaluate:

2.3.1.1. Safety procedures for launching radioactive material and contingency plans for responding to a radiological mishap.

2.3.1.2. Safety measures to prevent radiological mishaps.

2.4. Space Wing Commanders (SW/CC) Will:

2.4.1. Comply with **Table 2.2**, Nuclear Safety Review, Approval, and Reporting Procedures. (T-1)

2.4.2. Develop and exercise radiological safety and contingency plans for launch-related radiological mishaps. (T-1)

2.4.3. Review radiological issues at launch readiness reviews for launches containing radioactive material. (T-2)

2.4.4. Launches containing radioisotope materials must have an appropriate safety review (e.g., Safety Analysis Summary (SAS), Environmental Impact Statement (EIS)) as required and be in compliance with the risk constraints found in 3.3. (T-2)

2.5. Range Users.

2.5.1. Range users that launch, develop, test, or operate any programs or systems that use radioactive material in space or missile systems will: (T-1)

2.5.1.1. Comply with **Table 2.2**, Nuclear Safety Review, Approval, & Reporting Procedures.

2.5.1.2. Notify HQ AFSEC/SES as early as possible in the development or acquisition phase of the program of the potential use of radioactive material that may exceed the threshold requiring a Safety Analysis Summary (SAS) or if the mission will involve a reactor or fission device.

Table 2.2. Nuclear Safety Review, Approval, & Reporting Procedures.

STEP	A	B	C	D
	Who	**What**	**To**	**When**
1	Range Users	Provides initial notification of potential use of radiological materials (T-1)	HQ AFSEC /SES	As early as possible in the acquisition process.
2		Forecasts and reports all launches using radioactive quantities greater than 0.1 % of the A2 value. (T-0)		Quarterly.
3		Prepares and sends a Safety Analysis Summary (if required). (T-0)		At least 180 calendar days before launch for ASD (NBC) approval.
4		If INSRP, then provides technical support documentation (T-2)		At the end of NEPA process with regular updates.
5		Provides technical support documentation. (T-3)	Space Wing Safety	As requested.
6	HQ AFSEC /SES	Evaluates safety analysis. If a program needs higher approval, establishes Air Force safety position and sends nuclear safety launch approval request. (T-1)	ASD (NCB)	At least 150 calendar days before launch.
7	Space Wing Commander	Ensures the launch of radioactive materials or nuclear systems has required approvals. Reviews radiological issues at launch readiness review. (T-0)	HQ AFSEC /SES	At least 1 to 2 calendar days before launch.

2.5.1.3. Each quarter forecast and report, all missions using radioactive quantities greater than 0.1% of the A2 values listed in the IAEA's SSR-6, Section IV, Table 2, to HQ AFSEC/SES. (T-0) See **Attachment 3** of this manual for the report format.

2.5.1.4. Ensure coordination with higher authorities, per DoDD 3200.11, *Major Range and Test Facility Base,* and DoDI 3100.12, *Space Support*, is accomplished. (T-0)

2.5.1.5. Provide technical support to HQ AFSEC/SES and the Space Wing Safety Office for review early in the mission to support Space Wing Commander's launch decision authorities for US government missions. (T-3)

2.5.1.6. If requested, in addition to the SAS, provide Space Wing Safety Office with documentation on specifications of any subsystems designed to eliminate or minimize release of radioisotopes in launch mishap scenarios (e.g., overpressure, impact, thermal, reentry environments). Allow Launch Safety to review design changes and testing of these systems. Provide Launch Safety with any test plans, reports, test failures, and design reviews associated with containment subsystems, in a timely manner to allow the reviewers to understand and evaluate the information, technology, and the most current science related to the safety of the launch. (T-3)

Chapter 3

NUCLEAR SAFETY REVIEW AND LAUNCH APPROVAL INSTRUCTIONS

3.1. Assistant Secretary of Defense, Nuclear, Chemical & Biological ASD (NCB) Launch Approval. HQ AFSEC/SES will obtain nuclear safety launch approval from the ASD (NCB), when the radioactive material quantity exceeds the A2 value listed in Section IV, Table 2 of the IAEA SSR-6.

3.2. Launch Readiness Review. SW/CC's launch readiness reviews will include the following:

3.2.1. The types and quantities of radiological materials on board the missile or launch vehicle and payload. (T-3)

3.2.2. Assessment of launch radiological safety plans and procedures. (T-3)

3.2.3. Review of plans and operations in place, to include coordination with external agencies (Department of Energy, National Aeronautics and Space Administration (NASA), US Navy, etc.), regarding contingency, clean up, or recovery plans. (T-3)

3.2.4. Launch approvals when required (e.g. Presidential, ASD (NCB)). (T-0)

3.2.5. Ensure launches containing radioisotope materials have an appropriate safety review (e.g., Safety Analysis Summary (SAS), Environmental Impact Statement (EIS)) as required. (T-0)

3.2.6. Launch is in compliance with the following risk constraint. (T-2)

3.3. R Risk Constraint. The risk constraint to a member of the general public shall not exceed an individual Probability of Cancer Casualty (P_{CancerC}) of 1×10^{-6} (one in one million) with a confidence level of 90%. This carries with it an overall mean maximum individual effective dose goal of less than or equal to 0.1 roentgen equivalent man (rem) or 100 millirem (mrem) per mission. The overall mean maximum individual effective dose is the mean of the calculated maximum effective doses, based on various launch vehicle failure modes resulting in release of radioisotopes, received by the maximally exposed individual for a given mission. See **Attachment 4** for process examples.

3.3.1. Each mission should not exceed the overall mean maximum individual effective dose goal of 100 mrem. However, if a mission exceeds the dose goal, the SW/CC may approve the launch after additional safety analysis. The SW/CC must consider how the additional radiological risk contributes to the radioisotope launch risks and additional safety analyses and plans. This includes but is not limited to the impacts of planned mitigation efforts and target organs of the mission radioisotopes.

3.3.2. Assess the P_{CancerC} as 1.2 times the Probability of a Latent Cancer Fatality (P_{LCF}). This value provides the P_{CancerC} associated with a projected 50-year cumulative increase in risk for fatal and non-fatal cancers (i.e., a casualty). This P_{CancerC} is not aggregated with other mission risks.

3.3.3. General public risk that exceeds a P_{CancerC} of 1×10^{-6} requires SW/CC waiver approval. When the general public risk exceeds a P_{CancerC} of 100×10^{-6}, AFSPC/CC approval is required. The SW/CC shall notify AFSEC/SES before allowing launches that exceed a P_{CancerC} of 1×10^{-6}.

3.3.4. The SW/CC may consider collective or population effective doses. However, they shall not replace the risk constraint criteria. Collective effective doses have significant uncertainty and are not anticipated to significantly contribute to the casualty risk associated with radioisotope launch hazards.

3.4. Safety Analysis Summary (SAS). Range Users will prepare a SAS if the mission will involve a reactor, fission device, or for any planned launch of radioactive material when the total quantity of radioactive material exceeds the A2 values listed in the International Atomic Energy Agency's (IAEA) Regulations for the Safe Transport of Radioactive Material, SSR-6 Section IV, Table 2. (T-0) Prepare the SAS according to **Attachment 2** of this manual and send to HQ AFSEC/SES.

3.4.1. For mixed isotopes, follow SAS requirement calculation in **Attachment 2, para A2.5**.

3.4.2. If the INSRP creates a Safety Evaluation Report (SER), this report, along with the referenced Final Safety Analysis Report (FSAR), will be sufficient to meet the SAS requirement.

3.5. Range User technical support during INSRP empanelment. In the event of INSRP empanelment, in addition to **paragraph 2.5.1.6**., provide ongoing access to design, tests, analyses, results, and reports as early as possible in the development or acquisition phase of the program, to allow for HQ AFSEC/SES to conduct independent review, to verify, and to evaluate the range user's safety reports. The Nuclear Safety Databook; Environmental Impact Statement (EIS); preliminary, draft, and final Safety Analysis Reports (SAR); and associated Technical Interchange Meetings (TIM) normally meet these requirements. (T-2)

3.5.1. Provide initial range user's estimates, test plans, analyses, and results to Space Wing Safety Office at the end of the National Environmental Policy Act (NEPA) review process or three years from the intended launch window, whichever is later. (T-2)

3.5.2. Provide regular updates, as agreed upon, to Space Wing Safety Office as tests and analyses are conducted and results are finalized by the range user. (T-2)

3.5.3. Provide answers to questions or requests for data from Space Wing Safety Office or HQ AFSEC/SES within 30 calendar days of request. (T-3)

3.5.4. TIMs include the subject matter experts from both the mission range user and the INSRP working groups. The subjects of these TIMs may include nuclear systems, spacecraft, launch vehicle, safety subsystems, overall risk, and mishap hazards including overpressure, impact, thermal, reentry, and others as requested by HQ AFSEC/SES. (T-2)

JOHN T. RAUCH
Major General, USAF
Air Force Chief of Safety

Attachment 1

GLOSSARY OF REFERENCES AND SUPPORTING INFORMATION

References

Presidential Directive/National Security Council Memorandum-25, *Scientific or Technological Experiments with Possible Large-Scale Adverse Environmental Effects and Launch of Nuclear Systems into Space*, dated 14 December 1977 (as modified 8 May 1996)

DoDD 3100.10, *Space Policy*, 18 October 2012

DoDD 3200.11, *Major Range and Test Facility Base*, 27 December 2007

DoDI 3100.12, *Space Support*, 14 September 2000

AFPD 91-1, *Nuclear Weapons and Systems Surety*, 30 November 2016

AFI 48-148, *Ionizing Radiation Protection*, 20 November 2014

AFMAN 40-201, *Radioactive Materials (RAM) Management*, 29 March 2019

AFI 33-360, *Publications and Forms Management*, 1 December 2015

AFMAN 33-363, *Management of Records*, 1 March 2008

32 Code of Federal Regulations Part 989, Environmental Impact Analysis

Title 42, United States Code, Section 2121, Authority of Commission

Regulations for the Safe Transport of Radioactive Material, Specific Safety Requirements, International Atomic Energy Agency (IAEA), Safety Standards No. SSR-6, 2018 Edition

1990 Recommendations of the International Commission on Radiological Protection, Annuals of the ICRP, Publication 60, 1991

The 2007 Recommendations of the International Commission on Radiological Protection, Annuals of the ICRP, Publication 103, 2007

Final Environmental Impact Statement for the Mars 2020 Mission, NASA, Nov 2014

Final Safety Analysis Report for the Mars Science Laboratory MMRTG Launch Approval, Sandia National Laboratories, SAND2010-5559, Aug 2010

Adopted Forms

Air Force Form 847, *Recommendation for Change of Publication*

Terms

A1 and A2—refer to the basic radionuclide values of radioactive material as established by the IAEA to determine activity limits and packaging requirements for the safe transport of specific nuclear isotopes (IAEA Regulations for the Safe Transport of Radioactive Material, SSR-6, Section IV "Activity Limits and Classifications", Table 2 "Basic Radionuclide Values", p. 25; 2018). The A2 values are used by PD/NSC–25 as the bases to set a threshold for INSRP empanelment and quarterly reports. This manual uses the A2 values to set a threshold for SAS reports, as shown in **Table 2.1**. This manual does not use the A1 value.

Abbreviations and Acronyms

AF—Air Force

AFI—Air Force Instruction

AFPD—Air Force Policy Directive

AF/SE—Air Force Chief of Safety

AFSEC—Air Force Safety Center

AFSEC/SES—Air Force Safety Center, Space Safety Division

AIC—accident initiating conditions

ASD (NCB)—Assistant to the Secretary of Defense (Nuclear, Chemical & Biological Defense Programs)

DoD—Department of Defense

DoDD—Department of Defense Directive

DoDI—Department of Defense Instruction

EIS—Environmental Impact Statement

FSAR—Final Safety Analysis Report

HE—health effects

HQ AFSEC/SES—Headquarters, Air Force Safety Center Space Safety Division

IAEA—International Atomic Energy Agency

INSRP—Interagency Nuclear Safety Review Panel

LCF—latent cancer fatality

MAJCOM—Major Command

MID—maximum individual dose

mrem—millirem or one thousandth of a rem

NASA—National Aeronautics and Space Administration

NEPA—National Environmental Policy Act

NRC—Nuclear Regulatory Commission

OPR—Office of Primary Responsibility

P_A—accident probability

$P_{CancerC}$—probability of cancer casualty

P_{LCF}—probability of latent cancer fatality

P_R—conditional probability of release

P_{TR}—total probability of release

rem—roentgen equivalent man

SAR—Safety Analysis Report

SAS—Safety Analysis Summary

SER—Safety Evaluation Report

SSR—Specific Safety Requirements

SW/CC—Space Wing Commander

TBq—Terabecquerel

TIM—Technical Interchange Meeting

US—United States

Attachment 2

GUIDE FOR SAFETY ANALYSIS SUMMARY

A2.1. Safety Analysis Summary (SAS). When required range users will prepare the SAS according to this attachment and send to HQ AFSEC/SES.

A2.2. Mission Description. This description should include system, radioactive material, and mission profile descriptions.

A2.2.1. **System Description:**

A2.2.1.1. Program name.

A2.2.1.2. Launch vehicle description.

A2.2.1.3. Spacecraft or missile, and payload description.

A2.2.2. **Radioactive Material:** Describe each radionuclide separately, if applicable. Each radioactive material description consists of:

A2.2.2.1. Radionuclides.

A2.2.2.2. Modes of decay and associated energy intensities.

A2.2.2.3. Activity measured in Terabecquerels (TBq).

A2.2.2.4. Radiation exposure levels, with particular emphasis on areas accessible to personnel.

A2.2.2.5. Proposed use.

A2.2.2.6. Location on launch vehicle and payload.

A2.2.2.7. Manufacturer and source identification number.

A2.2.2.8. Nuclear Regulatory Commission or Agreement State sealed source and device registry number and the license or permit authorizing possession, if applicable.

A2.2.2.9. Source construction, including the chemical and physical form.

A2.2.2.10. Construction materials.

A2.2.2.11. Dimensions.

A2.2.2.12. Design criteria.

A2.2.2.13. Other information pertinent to assessing source integrity in normal and extreme operating conditions and potential mishap environments.

A2.2.3. **Mission Profile:**

A2.2.3.1. Launch facility identification.

A2.2.3.2. Proposed launch date.

A2.2.3.3. Launch azimuth.

A2.2.3.4. Mission profile description, including orbital or flight parameters.

A2.2.3.5. Mission duration.

A2.2.3.6. Impact predictions, if applicable.

A2.3. Nominal Mission Analysis. This analysis should address:

A2.3.1. Nuclear and radiation safety considerations throughout the mission, including handling from installation through flight and post-flight.

A2.3.2. Disposing of radioactive material, if applicable. Identify the license or permit under which recovered materials will be received, if applicable.

A2.4. Potential Mishap Evaluation. This evaluation should address:

A2.4.1. All mission phases, including prelaunch, launch, on orbit, reentry, impact, and post impact.

A2.4.2. Potential mishap scenarios, environments, and contingency options.

A2.4.3. Mission failure evaluation, including launch vehicle, payload, and source failure mode analyses and associated probabilities.

A2.4.4. Source response to accidents and potential consequences to the public and the environment.

A2.4.4.1. Mean maximum individual effective dose, probability of cancer casualty and confidence level as required.

A2.4.4.2. Potential for criticality of fissile material during potential mishaps.

A2.4.5. Any additional information pertinent to the SAS.

A2.5. Mixed Isotopes.

A2.5.1. When using several isotopes or a mixture of isotopes, base the required nuclear safety review on the normalized total quantity of radioactive material present, measured in Terabecquerels (TBq). The normalized total is the sum of the ratios of the individual isotopes to their respective A2 threshold quantities as shown below in **Mixed Isotopes**. If the normalized totals exceed 1.00, a SAS is required.

Mixed Isotopes.

$$\frac{\text{Isotope A (TBq)}}{\text{Threshold A (TBq)}} + \frac{\text{Isotope B (TBq)}}{\text{Threshold B (TBq)}} + \frac{\text{Isotope C (TBq)}}{\text{Threshold C (TBq)}} + \ldots < 1.00$$

Example:

Isotope A (TBq) = 1.2×10^{-4} of Pu-238
A2 Threshold for A (TBq) = 3×10^{-3} *(or 0.003)*

Isotope B (TBq) = 0.5 of Nb-95
A2 Threshold for B (TBq) = 1×10^{0} *(or 1.0)*

Isotope C (TBq) = 7.0 of Be-7
A2 Threshold for C (TBq) = 2×10^{1} *(or 20)*

1.2×10^{-4} TBq of Pu-238 is 0.00012 TBq/0.003 or 4% of the analysis threshold limit for Pu-238.

0.5 TBq of Nb-95 is 0.5 Tbq/1.0 Tbq, or 50% of the analysis threshold limit for Nb-95.

7.0 TBq of Be-7 is 7.0 TBq/20 TBq, or 35% of the analysis threshold limit of Be-7.

4% + 50% + 35% = 89% or 0.89 < 1.00

Therefore, the normalized total is 89% and a SAS is not required.

Attachment 3

LAUNCH FORECAST REPORT FORMAT

A3.1. Launch Forecast Report: Forecast of all scheduled missions meeting radioactive materials reporting criteria during the next quarter including the potential use of space reactor systems (fission device) or radioactive material that may exceed 0.1 % of the A2 threshold. HQ AFSEC/SES must receive the report at least 15 calendar days before the start of each calendar-year quarter. The forecast should include:

A3.1.1. Program name.

A3.1.2. Launch vehicle, site, and date.

A3.1.3. Impact area or orbital parameters.

A3.1.4. Specific radioisotopes and associated activities measured in TBq.

A3.1.5. Type of nuclear system or device, if applicable.

Attachment 4

RADIOLOGICAL LAUNCH RISK CONSTRAINT

A4.1. This attachment shows the three tests associated with the launch risk constraint and provides an example for each test. If a range user does not provide this type of information through their normal safety analysis process, the range user will need to arrange with HQ AFSEC/SES or Space Wing Safety a means of providing this data.

A4.2. Radiological launch risk constraint tests:

A4.2.1. **Test 1. Probability of cancer casualty**, $P_{\text{CancerC}} \leq 1 \times 10^{-6}$.

A4.2.1.1. Test 1 provides the probability of an individual developing cancer in the 50 years following a launch accident.

A4.2.2. **Test 2. Confidence Level,** $(P_{\text{CancerC}}) \geq 90\%$.

A4.2.2.1. Test 2 ensures the calculated confidence level of Test 1 is greater than or equal to 90%.

A4.2.3. **Test 3. Dose**, $D_{\text{Mean Maximum Individual Effective Dose}} \leq 100$ mrem/mission.

A4.2.3.1. Test 3 provides the overall mean maximum individual effective dose goal should be less than or equal to 100 mrem per mission, based on failure modes resulting in release received by the maximally exposed individual.

A4.2.4. The following **Test 1**, **Test 2**, and **Test 3** provide an example for each of the risk constraint tests.

Test 1, Probability Individual Cancer Casualty risk calculation example:

The probability of cancer casualty, $\boldsymbol{P}_{\text{CancerC}} \leq 1 \times 10^{-6}$, can be calculated using information normally provided by the range user in documents such as the Environmental Impact Statement (EIS) and/or the Safety Analysis Report (SAR). $\boldsymbol{P}_{\text{CancerC}}$ is a 50-year cumulative risk that any single person will suffer a cancer related consequence.

$$\text{Risk} = \text{Probability} \times \text{Consequence}$$
$$\text{Risk} = \boldsymbol{P}_{\text{TR}} \times \boldsymbol{P}_{\text{LCF}}$$

Total probability of release, $\boldsymbol{P}_{\text{TR}},$ is defined as the product of the mean accident probability, $\boldsymbol{P}_{\text{A}}$, and the conditional probability of release, $\boldsymbol{P}_{\text{R}}$.

$$\boldsymbol{P}_{\text{TR}} = \boldsymbol{P}_{\text{A}} \times \boldsymbol{P}_{\text{R}}$$

The probability of developing a Latent Cancer Fatality, $\boldsymbol{P}_{\text{LCF}}$ following exposure to released radioisotopes may be based on the International Commission on Radiological Protection (ICRP) Publication 60 factor of 6.00E-04 health effect, **HE** per person-rem. A different $\boldsymbol{P}_{\text{LCF}}$ may be used based on radiological isotope or target organ effects, if appropriately justified.

Nuclear payload missions usually provide an estimate of the maximally exposed individual's dose given a release during each distinct phase of flight (e.g., early, late ascent, suborbital, orbital, and long-term reentry cases).

$$\boldsymbol{P}_{\mathrm{LCF}} = \mathbf{HE} \times \mathbf{MID}$$

The individual Probability of Cancer Casualty, $\boldsymbol{P}_{\mathrm{CancerC}}$ is assessed as 1.2 times the $\boldsymbol{P}_{\mathrm{LCF}}$ (ICRP, Pub. 60). This additional factor is used to account for non-fatal cancers and hereditary risk factors.

$$\boldsymbol{P}_{\mathrm{CancerC}} = \boldsymbol{P}_{\mathrm{TR}} \times 1.2 \times \boldsymbol{P}_{\mathrm{LCF}}$$

$$\boldsymbol{P}_{\mathrm{CancerC}} = \boldsymbol{P}_{\mathrm{TR}} \text{ x } 1.2 \times \mathbf{HE} \times \mathbf{MID}$$

For example, the Mars 2020 EIS, Table 4-3, provides the total probability of release for each mission phase based on the accident probability and conditional probability of release, given an accident has occurred. Overall mission values are weighted by total probability of release for each mission phase.

Table data derived from Mars 2020 EIS, Table 4-3			
Mission Phase	Accident Probability, $\boldsymbol{P}_A$	Conditional Probability of Release, $\boldsymbol{P}_R$	Total Probability of a Release, $\boldsymbol{P}_{TR}$
0: Pre-Launch	3.30E-05	3.30E-01	1.10E-05
1: Early Launch	3.10E-03	2.80E-02	8.80E-05
2: Late Launch	3.60E-03	2.10E-03	7.70E-06
3. Suborbital	1.30E-02	1.30E-03	1.50E-05
4. Orbital	4.70E-03	5.60E-02	2.60E-04
5. Long-term Reentry	1.00E-06	9.40E-02	9.40E-08
Overall Mission	**2.50E-02**	**1.60E-02**	**3.80E-04**

Additionally, the Mars 2020 EIS, Table 4-4, provides the mean **MID** for each mission phase along with the associated probability of release. Overall mission values are weighted by total probability of release for each mission phase.

Table data derived from Mars 2020 EIS, Table 4-4		Maximum Individual Dose (MID) in rem
Mission Phase	Total Probability of Release ($\boldsymbol{P}_R$)	Mean
0: Pre-Launch	1.10E-05	2.90E-04
1: Early Launch	8.80E-05	6.00E-02
2: Late Launch	7.70E-06	1.60E-05
3. Suborbital	1.50E-05	4.30E-02
4. Orbital	2.60E-04	5.00E-04
5. Long-term Reentry	9.40E-08	8.00E-04
Overall Mission	**3.80E-04**	**1.60E-02**

Using the Mars 2020 EIS example data along with the ICRP 60 **HE** factor, the $\boldsymbol{P}_{\text{CancerC}}$ may be calculated:

$$\boldsymbol{P}_{\text{CancerC}} = 3.8\text{E-}04 \times 1.2 \times 6.0\text{E-}04 \times 0.016$$
$$\boldsymbol{P}_{\text{CancerC}} = 4.4\text{E-}09$$

The mean risk value or $\boldsymbol{P}_{\text{CancerC}}$ for this mission, 4.40E-09 (4.4 in a billion) is less than the mean risk constraint of 1E-06 (one in a million).

Test 2, Confidence Level calculation example:

Confidence Level, ($\boldsymbol{P}_{\text{CancerC}}$) ≥ 90% can be established by using information normally provided by the range user in documents such as the Environmental Impact Statement (EIS), the mission Databook and the Safety Analysis Report (SAR).

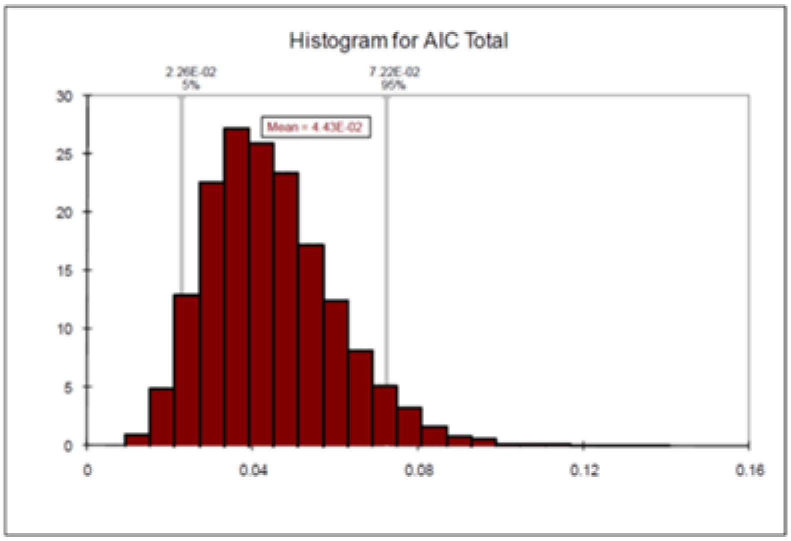
For example, most missions discuss uncertainty in the risk assessment results and have provided that this uncertainty is dominated by the associated launch vehicle accident probabilities. Dominant launch vehicle accident probability uncertainties are useful to examine those statistics and verify the confidence level.

Normally an uncertainty analysis is provided describing launch vehicle accident scenarios. Information may be included that discusses the range of uncertainty obtained for all accident outcomes with key uncertainty distribution parameters for all the accident initiating conditions.

The example accident initiating conditions (AIC) table below provides a mean estimate of that distribution as 4.43E-02 (±1.54E-02). A 90% confidence interval of the overall probability spans from 2.26E-02 to 7.22E-02 approximately. The distribution is moderately skewed and is evident in the histogram in the graph that follows.

Example Graph of AIC Distribution Parameters

Distribution Parameters	AIC Total
Mean	4.43E-02
Std. Deviation	1.54E-02
Variance	2.36E-04
Skewness	0.75
Kurtosis	3.97
Range Factor	1.79
Mode	3.89E-02
5% percentile	2.26E-02
10% percentile	2.63E-02
15% percentile	2.89E-02
20% percentile	3.10E-02
25% percentile	3.31E-02
30% percentile	3.52E-02
35% percentile	3.69E-02
40% percentile	3.87E-02
45% percentile	4.06E-02
Median	4.24E-02
55% percentile	4.44E-02
60% percentile	4.64E-02
65% percentile	4.85E-02
70% percentile	5.08E-02
75% percentile	5.36E-02
80% percentile	5.64E-02
85% percentile	6.01E-02
90% percentile	6.50E-02
95% percentile	7.22E-02



Example Graph of AIC Distribution Parameters

For this example, these statistics are generated via the Program's launch vehicle accident Monte Carlo simulation software. Since the Program utilized a 90% Confidence Interval to generate the accident statistics, they have met the criterion.

Test 3, Dose calculation example:

Dose, $\boldsymbol{D}_{\text{Mean Maximum Individual Effective Dose}} \leq 100$ mrem/mission can be established by using information normally provided by the range user in documents such as the Environmental Impact Statement (EIS) or the Final Safety Analysis Report (FSAR).
As shown in the test one example the overall mission mean maximum individual effective dose is usually provided in a summary table in the EIS and can be found in the FSAR.
Mars 2020's EIS, Table 4-4 provides a value of 0.016 rem (16 mrem) for the $\boldsymbol{D}_{\text{Mean Maximum Individual Effective Dose}}$. The FSAR will likely refine this value.
The value of 16 mrem is less than the goal limit of 100 mrem, therefore it meets the criterion.